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The Magnitude of Snowmelt and Rainfall Interception by Litter in Lodgepole Pine and Spruce-Fir Forests in Wyoming

Litter interception is the process whereby water is retained in the litter and subsequently evaporated. The proportion of a particular moisture input intercepted by litter depends on the quantity, duration, and intensity of input; the water absorption tendencies of the litter; the weight and storage capacity of the litter; and the moisture content of the litter when input begins. Although the importance of litter as a modifier of water flux is well known (Lowdermilk, 1930; Johnson, 1940; Kittredge, 1948; Rowe, 1955; Blow, 1955; and others), data are lacking for the central and northern Rocky Mountain region. This report considers the magnitude of forest litter interception in the Medicine Bow Mountains, southeastern Wyoming. Interception is estimated for both the snowmelt and summer rainfall periods.

The study was conducted in the Nash Fork Creek Watershed, a portion of the Snowy Range Water Resource Observatory (Rechard, 1969), located approximately 64 km west of Laramie, Wyoming. The watershed covers about 1874 ha and ranges in elevation from about 2590 m to 3353 m. The higher portion receives about 76 to 102 cm of precipitation annually, the lower portion from 38 to 51 cm; most of the precipitation occurs as snow. The soils are a grey-wooded type, alfisols (Western Soil and Water Research Committee, 1964), and are generally shallow, rocky, and poorly developed (Mears, 1953). Lodgepole pine forest (*Pinus contorta* ssp. *latifolia* (Engelm. ex Wats.) Critchfield) covers about 22 percent of the watershed, occurring mostly as continuous young stands at lower elevations; spruce-fir forest (*Picea engelmannii* Parry ex Engelm. and *Abies lasiocarpa* (Hook.) Nutt.) covers approximately 38 percent of the watershed and dominates the upper regions. Many lakes and meadows interrupt the subalpine forest, and near timberline the trees occur as widely dispersed krummholz.

Methods

Three kinds of data were obtained to estimate the magnitude of litter interception: throughfall, hydrologic characteristics of the litter, and the total litter weight per unit area. To estimate throughfall, 25 raingages were constructed of No. 10 cans, with aluminum foil funnels, and were located randomly in each of eight 0.1 acre (404 m^2) stands, four in pine forest and four in spruce-fir forest (Table 1). Two gages were

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TABLE 1. Characteristics of stands used for hydrologic investigations. Each stand was 0.1 acre ($404\ m^2$).

Stand	Elevation	% Slope	Slope Exposure	Tree Basal Area (m^2)	Age[a]	Canopy Height (m)	Litter Height (kg/ha)
Lodgepole 1	2789 m	7	E	30	84	23	11,700
Lodgepole 2	2804 m	19	E	9	81	18	8,412
Lodgepole 3	2819 m	21	SW	21	77	19	11,935
Lodgepole 4	2834 m	42	N	20	80	19	12,333
Spruce-Fir 1	3119 m	14	S	33	279	26	20,223
Spruce-Fir 2	3119 m	16	SW	23	162	27	16,499
Spruce-Fir 3	3149 m	10	W	28	264	24	15,575
Spruce-Fir 4	3155 m	26	NE	27	145	24	15,987

[a] Average age of five canopy trees.

located in adjacent openings near each stand to estimate gross rainfall. The cans were tested with standard U.S. Weather Bureau eight-in gages; the results were comparable.

Hydrologic characteristics of the litter. The maximum moisture-holding capacity of litter, defined as the amount of water the litter retains after being saturated and all excess gravitational water has drained off, was determined in each of the eight stands using the methods of Clark and Ffolliott (1969). Square metal frames, 15x15x15 cm and open at both ends, were forced through the litter to the soil. Approximately eight to 11 liters of water were sprinkled slowly into the frames. Plastic and aluminum foil were then secured over the frame opening to retard evaporation while the litter drained for 24 hours. The litter was then removed by conventional layers: L layer (unaltered litter), F layer (partly decomposed litter still recognizable as to origin), and H layer (litter unrecognizable as to origin). Usually the H layer could be separated from the underlying soil without much difficulty. Each layer was placed in a plastic bag, weighed in the laboratory, and oven-dried at 65°C to a constant weight. Fifteen replications in each stand gave mean moisture-holding capacities (percent of dry weight) for each layer with standard errors that, within 95 percent confidence limits, were less than 10 percent of the mean.

To determine drying rates and the minimum field moisture content to which the litter dries, litter was sampled immediately after rainfall in the stands, and at 3, 5, 7, 9, 10, 12, 14 and 16 days thereafter as long as subsequent rain did not interrupt drying. Four samples of the litter were taken each sampling period to determine moisture content. To supplement the rainfall data 18 frames of the type described earlier were inserted through the litter in each stand. The enclosed litter was then saturated, left uncovered, and two frames sampled for litter moisture content at the various day increments listed above. The percentage of moisture retained after field drying is the minimum moisture content. The total storage capacity is the difference between the maximum and minimum moisture content of the litter.

Data were collected to examine the increase in moisture content of the litter for a given magnitude of actual throughfall, using a method modified from Helvey (1964). To estimate litter moisture before rain, four frames were forced through the litter into the soil and covered; no rainwater could reach the enclosed litter either by direct impact or surface runoff. The frames were rotated randomly each day during the month of July, but in August the frames were put in place only if rainfall seemed probable. The increase in moisture content was estimated by subtracting the before-rain moisture content from the after-rain moisture content, determined by inserting six frames as before after throughfall ceased, covering the frames to prevent evaporation, and weighing the litter 24 hours later.

A total of only eight measurable rainstorms occurred during the sampling period of June through August, 1970, in the lodgepole pine stands; 12 occurred in the spruce-fir stands. Some artificial watering was therefore employed to obtain additional data for determining the increase in moisture content of the litter for a given water input. Water was sprinkled into frames and the sampling procedure followed as described above. This was done in three stands of lodgepole pine (Nos. 1, 3, and 4, Table 1) and three spruce-fir (Nos. 2, 3, and 4, Table 1), using a total of 18 replications for each of the following amounts: 2.5 mm, 6 mm, 10 mm, 13 mm, and 19 mm; eight replications at 25 mm; and six replications at 38 mm, 50 mm, and 100 mm. Adequate samples were obtained (S.E. less than 10 percent of the mean moisture contents).

Litter weight estimation. Eight 0.1 acre (404 m^2) stands were selected in the spruce-fir community and 40 in the lodgepole pine community. The stands were located throughout the watershed and were selected to include a wide variation in elevation, slope, and aspect. Basal area, stand age (average of increment borings from five dominants), and average height of the dominant trees were determined in each stand. The metal frames described previously were used to sample litter weight. The frames were forced through the litter down to soil and the litter extracted. All samples were divided into the L, F, and H layers and placed into paper bags for drying, the depth of each layer being determined by averaging the depths on the four edges of the hole left by removal of the litter. Fifteen to twenty random samples gave estimates of the mean floor weight that have standard errors less than 10 to 15 percent of the means with 95 percent confidence. To determine if litter weight could be predicted, correlations between the depth and weight of the litter layers were calculated for both community types; multiple and stepwise regression procedures were applied to the lodgepole pine forest data, using the forest structure and age measurements as the independent variables and total litter weight as the dependent variable.

Results

Average throughfall was 60 percent of the gross precipitation in the four spruce-fir stands and 79 percent in the four lodgepole pine stands. Patric (1966) obtained similar results in the coniferous forests of southeastern Alaska.

Hydrologic characteristics of the litter. No significant differences were found in the maximum water-holding capacity of the litter in the four stands of lodgepole pine nor in the four stands of spruce-fir; the data were therefore grouped for further analysis. The maximum water-holding capacity of the lodgepole pine litter was determined to be 130 percent of its dry weight (S.E. = 4.6 percent); spruce-fir litter held 123 percent (S.E. = 3.7 percent). These values fall into the range of reported values for coniferous forests, which vary considerably (Table 2).

From analysis of variance of the total moisture held, the F layer was found to hold significantly more moisture per gram than either the L or H layers in both forest communities (Table 3). This was the case also for white pine litter in Massachusetts (Mader and Lull, 1968), although the H layer held more moisture per gram in Arizona ponderosa pine litter (Clary and Ffolliott, 1969).

TABLE 2. Maximum water-holding capacity of the litter in various coniferous forests.

Maximum Water-Holding Capacity[a]	Forest Type	Location	Reference
220	loblolly pine	South Carolina	Metz (1958)
205	white pine	Massachusetts	Mader & Lull (1968)
204	cedar-hemlock	Washington	Balci (1964)
180	pine-fir	California	Lowdermilk (1930)
161-179	fir	California	Kittredge (1955)
173	ponderosa pine	California	Kittredge (1955)
150	Douglas fir	California	Kittredge (1955)
130	lodgepole pine	Wyoming	this study
123	spruce-fir	Wyoming	this study
116	ponderosa pine	Arizona	Clary & Ffolliott (1969)

[a] Expressed as a percent of dry weight.

As expected, the L layer dried fastest in both communities, the H slowest (Fig. 1). Approximately 11 to 13 days were required for the total forest floor of lodgepole pine to reach a minimum field moisture content, and about 12 to 16 days were necessary in spruce-fir. Although varying climatic conditions affect evaporation, these rates are assumed typical since they were observed during both July and August. No data were found in the literature for drying-out rates in other western coniferous forests, but from 11 to 16 days were required for pine and hardwood in the east (Metz, 1958; Helvey, 1964, 1967). In general, most water loss (50 to 60 percent) occurred in the first four to six days, a feature which has been observed by others as well (Blow, 1955; Metz, 1958; Helvey, 1964, 1967; Helvey and Patric, 1965; Mader and Lull, 1968).

The minimum moisture content reached by the lodgepole pine litter was 17 percent of dry weight, and about 24 percent for spruce-fir litter (Table 3). Minimum values in the literature vary from 3 percent for hardwoods in Mississippi (Broadfoot, 1953) to 40 percent for eastern white pine in North Carolina (Helvey, 1967). No values have been reported for western coniferous forests to our knowledge.

The amount of water required to bring the litter from a minimum to maximum moisture content averaged about the same for both forest types, 13 mm (0.5 in) (Fig. 2). Although the frames prevented lateral flow, creating an artificial wetting

TABLE 3. Maximum water storage and maximum and minimum water content by layers in percent dry weight and mm of water.

	Maximum		Minimum		Maximum Moisture Storage
Layer	Percent Dry Weight	mm of Water[a]	Percent Dry Weight	mm of Water[a]	(mm of water[a])
Lodgepole					
L	124± 5	1.3	8± 2	0.1	1.2
F	138± 6	1.6	9± 2	0.1	1.5
H	129± 9	6.6	21± 7	1.1	5.5
L, F, H	130±10	9.5	17±10	1.3	8.2
Spruce-Fir					
L	102± 7	1.7	7± 1	0.1	1.6
F	150± 2	3.5	13± 3	0.3	3.2
H	118±11	7.6	29±11	1.9	5.7
L, F, H	123± 7	12.8	24± 5	2.3	10.5

[a] Based on the average kg/ha for each layer in respective forest type; maximum storage is estimated by subtracting the minimum moisture content from the maximum.

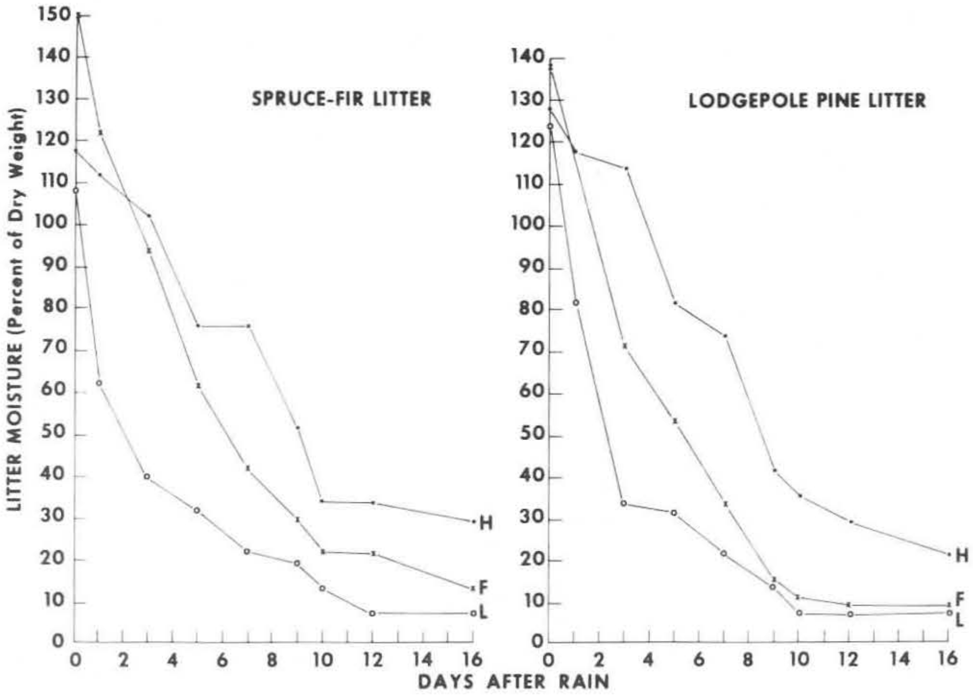

Figure 1. The average drying curves of the relatively unaltered litter (L), partly decomposed litter (F), and decomposed litter (H) in both spruce-fir and lodgepole pine forests.

situation, had the frames not been used and a larger area wetted, there would have been some run-on as well as run-off. The data obtained by artificial wetting were comparable to data obtained on the three occasions when rain over 13 mm occurred.

Litter weight estimation. The 40 lodgepole pine stands that were sampled varied in age from 71 to 265 years and in basal area from 6.9 to 32.0 m^2; the eight spruce-fir stands varied in age from 123 to 293 years and in basal area from 17.6 to 32.7 m^2. The highest average litter weight, 17,013 kg/ha, was found in the spruce-fir communities; the lodgepole stands averaged 12,113 kg/ha. The weights of the two communities are significantly different ($P=0.01$), which is not surprising considering that most of the spruce-fir stands were much older and have more biomass in the canopy. The H layer in both forest types accounted for approximately 60 to 70 percent of the total weight and 53 to 55 percent of the total depth.

The litter depths for the two communities, on the other hand, were not significantly different ($P=0.05$), spruce-fir averaging 3.8 cm and lodgepole pine 3.7 cm. This is of interest as the total litter weights were quite different. Balci (1964) obtained similar results with litter weights of 36,155 and 12,478 kg/ha in western hemlock-Pacific silver fir and western hemlock-Douglas fir forest, respectively, whereas the depth of both forests averaged about 15 cm. Balci attributed the higher weight of the hemlock-silver fir litter to the higher bulk density, and in fact we found the bulk density of the spruce-fir litter, composed of short needles, to be 32 percent higher than that of the lodgepole litter.

Correlation and regression analyses were done to determine if lodgepole pine

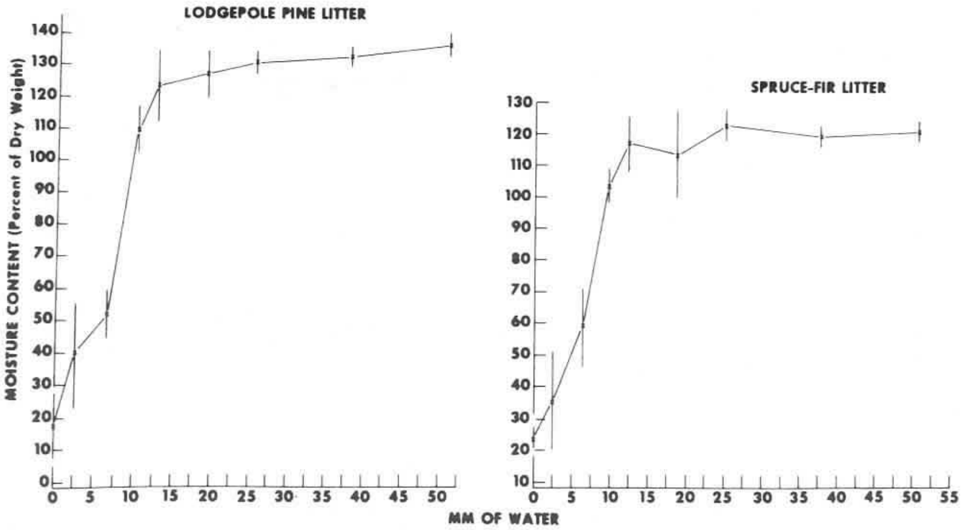

Figure 2. Moisture required for litter (L, F, and H) saturation in lodgepole pine and spruce-fir forests. Plotted points (with 95% C.I.) represent mean moisture contents of the litter after a known amount of water input.

litter weight could be predicted from easily measured variables. Although litter depth, stand basal area, and tree height were significantly correlated ($P=0.05$) to total litter weight, only 52 percent of the variation in litter weight was accounted for by these variables.[2] Elevation, slope, stand age, and tree density were not significantly correlated to total litter weight.

Litter storage capacity. With the data on litter weight and the maximum and minimum water-holding capacities, the maximum available moisture storage in the litter can be calculated. The total forest floor in lodgepole pine has an average maximum storage of approximately 8 mm, based on the average litter weight for the watershed; spruce-fir storage averages about 10 mm (Table 3). Theoretically, rainfall less than these amounts would be intercepted by the litter and subsequently evaporated. Figure 2 shows, however, that rainfall in excess of these maximum storage capacities was necessary for the litter to become saturated in the three stands of pine and three of spruce-fir where our experiments were conducted. Apparently the litter is somewhat hydrophobic, and with a 13 mm rainfall, three to five mm could infiltrate to the soil.

The moisture content of the litter was monitored during July and August, 1970, in both a spruce-fir and a lodgepole pine stand (Table 4). An average amount of precipitation occurred during this time. The litter in the spruce-fir stand reached a maximum moisture content, for the first time after the snowmelt water evaporated, on July 21 when throughfall totalling 15 mm raised the litter moisture content from a minimum to a maximum. The 15 mm, however, is in excess of the maximum available storage for the spruce-fir litter (10 mm), and not all of this input was intercepted. Only one other rain (15 mm) raised the litter moisture content from a

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[2] The regression equations can be found in Reynolds, James F., 1971, Moisture Interception by Lodgepole Pine and Spruce-Fir Litter in Southeastern Wyoming. M.S. Thesis, Department of Botany, University of Wyoming, 48 pp.

TABLE 4. Two-month precipitation data and moisture content of litter in both a spruce-fir (No. 4, Table 1) and a lodgepole pine (No. 3, Table 1) stand, 1970.

		Rainfall (mm)		Litter Moisture Content (% dry wt)	
Stand	Date	Gross	Throughfall	Before	After
Spruce-Fir	7-17	Trace	–	–	–
	7-21	28.7	15.7	25^{a}	125^{b}
	7-23	5.8	3.8	118	130^{b}
	7-31	7.9	6.4	58	129^{b}
	8- 5	Trace	–	–	–
	8- 8	7.4	3.0	38	85
	8-15	16.8	14.2	28^{a}	122^{b}
	8-23	36.3	18.3	40	130^{b}
Lodgepole Pine	7- 7	Trace	Trace	–	–
	7-14	Trace	Trace	18^{a}	25^{a}
	7-22	4.8	3.8	19^{a}	46
	8- 2	17.5	13.9	26^{a}	136^{b}
	8- 8	Trace	–	53	–
	8-23	Trace	Trace	18^{a}	26^{a}

[a] Within the 95 percent confidence interval on the average minimum.
[b] Within the 95 percent confidence interval on the average maximum.

field-dry condition to its maximum water-holding capacity. It is estimated that only about 10 to 18 mm of rainfall reached the soil during the summer of 1970 in this particular spruce-fir stand.

The lodgepole pine stand, located in the lower portion of the watershed, received only one rainfall sufficient for litter saturation. The litter in this stand was in a field-dry condition from about June 16 to July 22 when throughfall totalling four mm raised the moisture content to above minimum. By August 2, 11 days later, the litter had reached minimum moisture content again when throughfall totalling 14 mm raised the moisture content to maximum. The litter in this stand failed to reach maximum water-holding capacity again during August, thus having available storage for any rainfall that might have occurred. In this particular lodgepole pine stand it is estimated that about six mm of rainfall reached soil during the summer, 1970.

Considering the difference in mean litter weight, it is surprising to note that about 13 mm of water will raise the moisture content of the litter to field maximum in both forest types. Possibly, since the artificial saturation procedures we used did not include an increment between 10 and 13 mm, the lodgepole pine litter may require less than the 13 mm to reach maximum. Also, the spruce-fir litter has a higher bulk density and holds less water as a percent of its dry weight (Table 3).

Water retention by litter has been studied in several vegetation types. In general, the storage capacity of litter ranges from about 10 to 13 mm in eastern white pine (Mader and Lull, 1968) to approximately one mm in the pine barrens of New Jersey (Bernard, 1963). In the southern Rocky Mountain region, a maximum of about two mm of water can be held by Arizona ponderosa pine litter at saturation (Clary and Ffolliott, 1969), while Pringle manzanita litter and shrub live oak litter both averaged five mm (Garcia and Pase, 1967). These studies show a considerable range in the storage capacities of litter, and in some cases a significant amount of water could be intercepted during the year. In fact, Aldon (1968) found that ponderosa pine litter intercepted from 7 to 27 percent of the gross precipitation during a summer storm period in Arizona; in the southern Appalachians, Blow (1955) and Helvey (1964) report that only 2 to 5 percent of the annual rainfall is intercepted by litter.

Generalization to the Watershed

The Nash Fork Watershed has been mapped so that we can calculate the area covered by both pine and spruce-fir forest. Furthermore, we now have estimates of the average litter storage capacities in each forest type, as well as other hydrologic characteristics. Some generalizations about interception by forest litter in the entire watershed are now possible.

Snowmelt interception. The litter is undoubtedly saturated during the snowmelt period. The maximum amount of intercepted snowwater is calculated by multiplying the average maximum volume of water held per acre in each forest type by the number of acres covered by each type in the watershed. Approximately 28 acre-feet (34,537 m^3) of snowwater are intercepted and subsequently evaporated from pine forest litter and about 57 acre-feet (70,308 m^3) from spruce-fir litter, for a total of 85 acre-feet (104,845 m^3). Even if our estimate is low by 50 acre-feet, snowmelt interception by forest litter is very low compared to the typical spring runoff of 5000 to 8000 acre-feet (6.2 to 9.9 million m^3) (Rechard and Smith, 1972).

Rainfall interception. Estimating the significance of rainfall interception is less straightforward since the quantity and seasonal distribution of rainfall must be considered as well as the drying rate and the storage capacity of the litter in the particular area where rain occurs. To illustrate, rainfall reaching forest floor litter that has been wetted from an earlier rain will be intercepted according to the amount of available storage in the litter. This, in turn, is governed by the time lapse since the previous rain. Most of the moisture (40 to 60 percent) is evaporated from the litter in the first four to six days after saturation. Thus, if saturating rainfall occurred five days apart during a month, a large portion of the incoming precipitation would be intercepted; if saturating rain occurred daily, the rain would not be intercepted as the litter would not drop below its maximum available storage capacity.

Precipitation data on a daily basis for the summer of 1968 are available from a site at 3170 m in the watershed (Table 5). These data will be examined to estimate the significance of rainfall interception. Throughfall is approximated as 60 percent of gross rainfall in spruce-fir forest, the average for the four spruce-fir stands studied. Since the range was actually 41 to 85 percent in one stand (Table 4), the 60 percent average is only a rough estimate.

Precipitation increased from a low of 20 mm in June to 70 mm in August. In June, a total of six measurable rainshowers occurred, each of which resulted in throughfall of about four mm or less. All of these showers would have been completely intercepted since the maximum storage is 10 mm and the showers were separated sufficiently to prevent moisture buildup in the litter.

About the same pattern occurred in July. A total of nine rainshowers producing about 30 mm of water would have been intercepted by the spruce-fir canopy and the litter layers. The long drying period in the middle of the month is significant in providing storage in the litter for the rain in the latter portion of the month.

The wettest month, August, shows a different sequence. The first rain would have been intercepted, even though the litter would have been above field minimum from the rain on July 29 and 30. By August 8 the litter was at or near minimum

TABLE 5. Precipitation data at the Little Brooklyn Lake weather station for summer, 1968 (elevation ca. 3170 m). The precipitation is gross rainfall, the estimated throughfall is in parenthesis (60 percent of gross rainfall).

Day	June	July	August
1	.0 mm	.0 mm	.0 mm
2	.0	.0	.0
3	.0	.0	2.5 (1.5)
4	.0	3.8 (2.3)	.0
5	.0	6.4 (3.8)	.0
6	.0	.0	.0
7	.0	.0	.0
8	4.3 (2.6)	1.3 (0.8)	7.6 (4.6)
9	.0	.0	18.0 (10.9)
10	6.3 (3.8)	.0	6.4 (3.8)
11	.0	5.1 (3.1)	2.5 (1.5)
12	.0	.0	.0
13	.0	.0	3.3 (2.0)
14	.0	.0	3.8 (2.3)
15	.0	.0	1.3 (0.8)
16	.0	.0	.0
17	.0	.0	2.3 (1.4)
18	.0	.0	1.8 (1.1)
19	.0	.0	.0
20	.0	.0	.0
21	.0	.0	.0
22	1.3 (0.8)	1.3 (0.8)	1.8 (1.1)
23	.0	.0	2.0 (1.2)
24	3.1 (1.8)	.0	.0
25	2.5 (1.5)	5.0 (3.0)	.0
26	.0	1.3 (0.8)	.0
27	.0	.0	15.2 (9.1)
28	.0	.0	.0
29	2.5 (1.5)	1.3 (0.8)	2.0 (1.2)
30	.0	6.3 (3.8)	.0
31	–	.0	.0
Total	20.0 (12.0)	30.5 (18.3)	70.6 (42.4)

because of an eight-day drying period with only a very small shower (1.5 mm of throughfall). The shower on August 8 would have been intercepted. The following three days of rain would not have been completely intercepted because the moisture content of the litter would have reached maximum available storage with throughfall of 11 mm on August 9. Therefore, about 10 mm of water would have infiltrated to the soil from the 20 mm of throughfall occurring between August 8 and 11. With only one day of drying, at least part of the showers on August 13, 14, and 15 probably infiltrated also. The last six rainshowers were probably intercepted completely.

Soil moisture recharge from rainfall during the summer months is probably a rare occurrence in this region for either forest type. Six years of precipitation data from weather stations throughout the watershed show that of 217 rainshowers occurring from 1965 to 1970, 90 percent (or 195) were 13 mm or less. Our data suggest that the water in these showers would usually be intercepted by the canopy and litter layers of the vegetation. Of course, as discussed above, the periodicity of the showers must be considered. Although stemflow could be considered as another pathway to the soil, our observations suggest that it is not an important phenomenon in our area for soil moisture recharge during the summer.

The results reported herein have implications for cloud seeding, nutrient cycling, and vegetation growth. Cloud seeding has been suggested as a means of increasing precipitation in the Medicine Bow Mountains, but is it possible to produce rainfall with resulting throughfall exceeding the available storage capacity of the forest litter? For instance, a rainshower of 15 mm would be mostly intercepted by the canopy and litter without reaching soil. If rainfall of this magnitude is not possible, then it may be necessary to produce frequent showers, thereby facilitating infiltration through saturated litter. Winter cloud seeding may be more productive.

With regard to nutrient cycling, it is probable that litter decomposition occurs during the summer primarily after the litter is moistened by the periodic rains, but little if any leaching would occur as a result of rainwater movement from June through August. Further research is required to determine the extent of leaching by fall rainwater and spring snowmelt water, and the suitability of the cold, snowmelt-saturated litter for decomposer activity.

Finally, our results suggest that summer plant growth in the Nash Fork Creek Watershed must depend primarily on one major pulse of soil moisture from snowmelt, unless, of course, moisture in the litter is available to the plants. We are currently investigating this possibility.

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Literature Cited

Aldon, E. F. 1968. Moisture loss and weight of the forest floor under pole-sized ponderosa pine stands. J. Forest. 66: 70-71.

Balci, A. N. 1964. Physical, Chemical and Hydrological Properties of Certain Western Washington Forest Floor Types. Ph.D. Thesis. Univ. Washington, Seattle, Washington. 192 pp.

Bernard, J. M. 1963. Forest floor moisture capacity of the New Jersey pine barrens. Ecology 44: 574-576.

Blow, F. E. 1955. Quantity and hydrologic characteristics of litter under upland oak forests in eastern Tennessee. J. Forest. 53(2): 190-195.

Broadfoot, W. M. 1953. Moisture in Hardwood Forest Floor. U.S. Dept. of Agriculture, Forest Service, South. Forest Exp. Sta. Note 85. 1 p.

Clary, W. P., and P. F. Ffolliott. 1969. Water holding capacity of ponderosa pine forest floor layers. J. Soil and Water Conserv. 24(1): 20-21.

Garcia, R. M., and C. P. Pase. 1967. Moisture Retention Capacity of Litter under Two Arizona Chaparral Communities. U.S. Dept. of Agriculture, Forest Service, R. M. Forest Exp. Sta. Res. Note 85. 2 pp.

Helvey, J. D. 1964. Rainfall Interception by Hardwood Forest Litter in the Southern Appalachians. U.S. Dept. of Agriculture, Forest Service, S.E. Forest Exp. Sta. Res. Paper 8. 8 pp.

———. 1967. Interception by eastern white pine. Water Resources Res. 3(3): 723-729.

———, and J. H. Patric. 1965. Canopy and litter interception of rainfall by hardwoods of eastern United States. Water Resources Res. 1: 193-205.

Johnson, W. M. 1940. Infiltration capacity of forest soil as influenced by litter. J. Forest. 38: 520.

Kittredge, J. 1948. Forest Influences. McGraw-Hill Book Co., New York. 394 pp.

———. 1955. Litter and forest floor of the chaparral in parts of the San Dimas Experimental Forest. Hilgardia 23: 563-596.

Lowdermilk, W. C. 1930. Influences of forest litter on runoff, percolation, and erosion. J. Forest. 28: 474-491.

Mader, D. L., and H. W. Lull. 1968. Depth, Weight, and Water Storage of the Forest Floor in White Pine Stands in Massachusetts. U.S. Dept. of Agriculture, Forest Service, N.E. Forest Exp. Sta. Res. Paper 109. 35 pp.

Mears, B. 1953. Quaternary features of the Medicine Bow Mountains, Wyoming, pp. 81-84. IN: Guidebook 8th Annual Field Conference, Wyoming Geol. Assoc. and Univ. of Wyoming.

Metz, L. J. 1958. Moisture held in pine litter. J. Forest. 56: 36.

Patric, J. H. 1966. Rainfall interception by mature coniferous forest of southeastern Alaska. J. Soil and Water Conserv. 21: 229-231.

Rechard, P. A. 1969. Snowy Range Water Resource Observatory (A Progress Report). Water Resources Research Institute, University of Wyoming, Water Resources Series No. 15. 34 pp.

————, and V. E. Smith. 1972. Physical and Hydrometeorological Characteristics of the Snowy Range Observatory. Water Resources Research Institute, University of Wyoming, Water Resources Series No. 30. 168 pp.

Rowe, P. B. 1955. Effects of the forest floor on disposition of rainfall in pine stands. J. Forest. 53: 342-348.

Western Soil and Water Research Committee. 1964. Soils of the Western United States. A regional publication by the Western Land Grant Universities and Colleges with cooperative assistance by the Soil Conservation Service. U.S. Dept. of Agriculture, Washington State Univ., Pullman, Wash.

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